INTRODUCTION

to

ELECTRIC CIRCUITS

SEPTEMBER 1981

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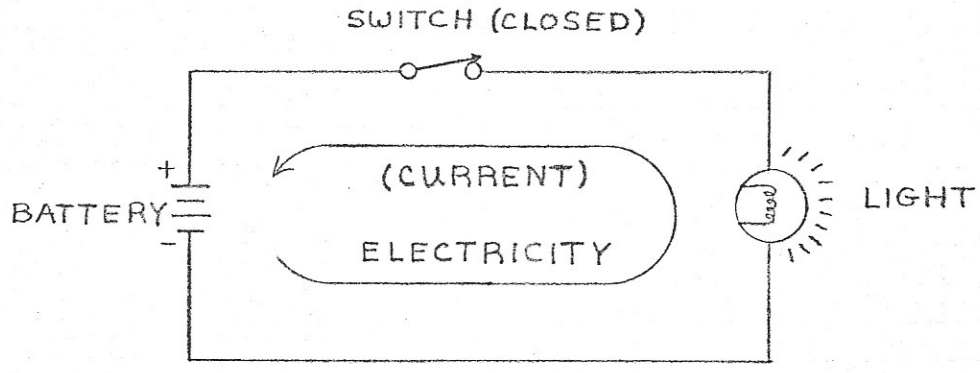
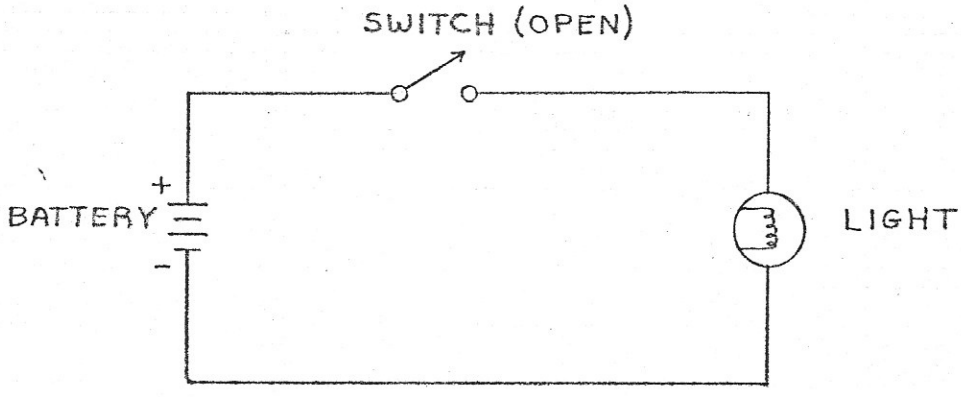
I. ELECTRIC CIRCUITS - Discussion

Circuit: An electric circuit is an unbroken path from one terminal of the power source through a device and back to the other terminal of the power source. Examples of power sources are batteries and the power lines outside of a building. When this path is broken, at any point, electricity (current) will not flow and the device will not operate. Including a switch in the path enables us to intentionally break or complete the path in order to control the device.



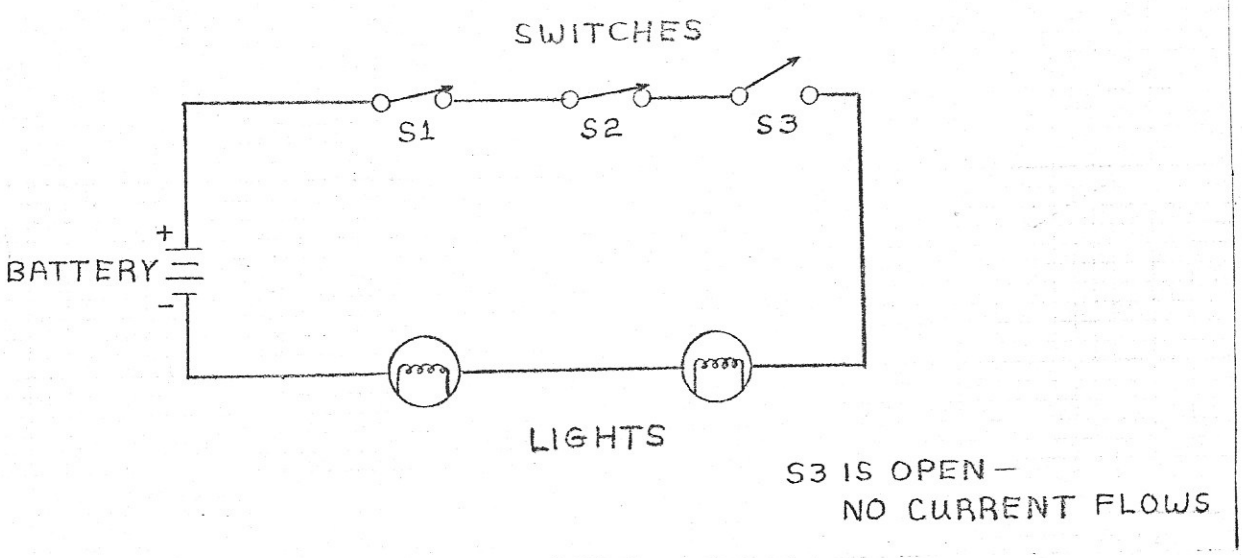
CIRCUIT (COMPLETE)



CIRCUIT (PATH BROKEN)

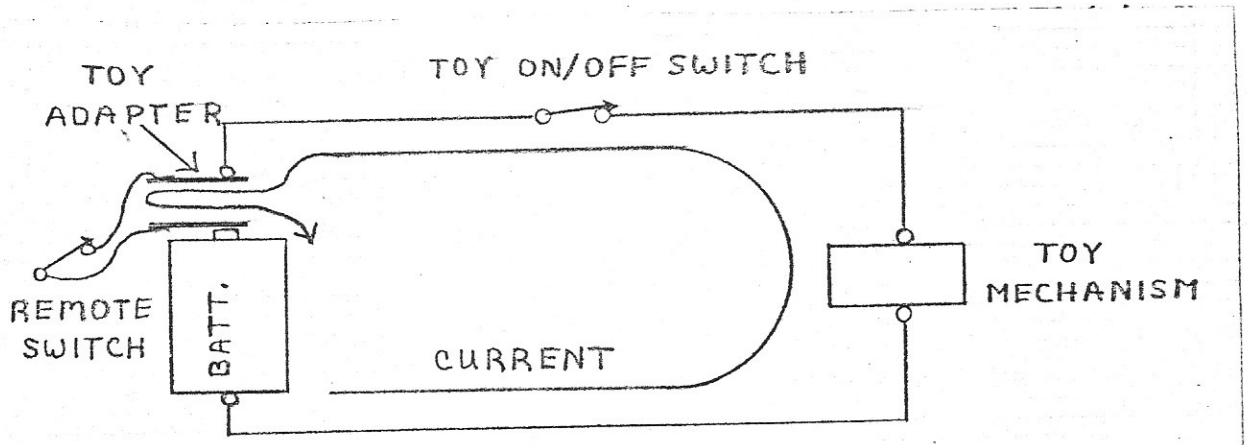
There are two types of circuits, Series and Parallel.

Series: In a series circuit all of the components are connected in line (series). All of the components must allow electricity to pass through them or the electricity will not flow.

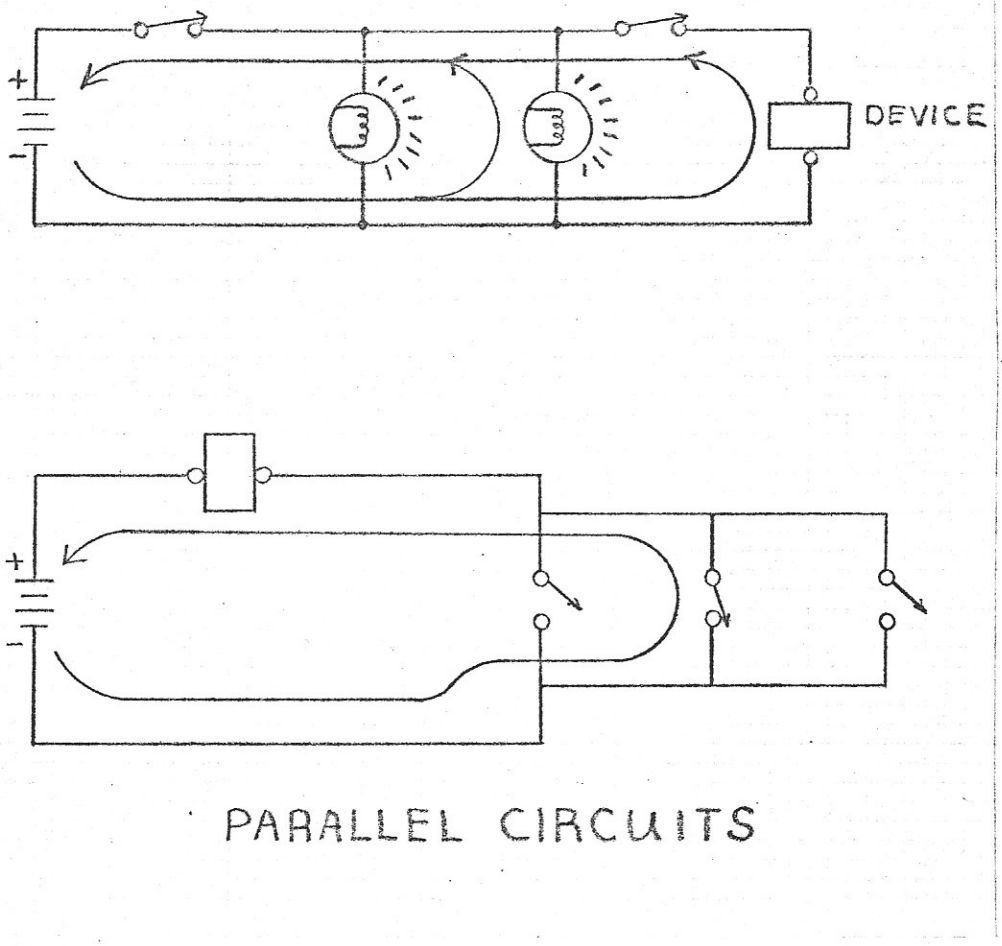


Series Circuit-Uses: Connecting switches in series will require that all of the switches must be closed before a device will operate.

An example is the toy adapter. Using the toy adapter effectively puts a second switch in series with the normal ON/OFF switch. Both switches must be activated before the device will operate.



Parallel: In a parallel circuit the components are connected in such a way that all of the components need not allow electricity to flow for the other components to work. This type of a circuit provides more than one possible path and electricity will flow in all of those that are unbroken.



PARALLEL CIRCUITS

Parallel Circuit-Uses: Connecting switches in parallel will enable closure of any one of the switches to operate a device irregardless of the position of the other switches.

This can be very useful in situations where the type or location of a switch makes it difficult for some users to operate whereas it is the preferred type or location for others. An example might be the push-button switches on the Apple

computer game paddles. In this case a jack can be installed in parallel with the paddle switch. Other types of switches can then be connected to the paddle through the jack, but do not need to remain connected in order for the normal switch to operate (as would be needed in a series circuit).

Another example is in the case where normal operation requires two switches to be activated at the same time, such as the SHIFT or CTRL and a character key on a computer terminal. These switches are momentary types. Connecting a latching type switch in parallel with the SHIFT and CTRL key switches will enable mouthstick users and others who have difficulty activating two switches simultaneously to operate the keyboard. The normal SHIFT and CTRL keys remain unaffected and available to those who do not require the modifications.

II. TERMINOLOGY & DEFINITIONS

Voltage (V): The potential to force current through a circuit. Even when the circuit is broken and no current is flowing the voltage (potential) still exists. Measured in volts.

Current (I): The actual flow of electricity through an unbroken circuit. Measured in amperes (Amps).

Resistance (R): How much any circuit component resists the flow of current. Measured in ohms (symbol = Ω). All components have some resistance; wire has very little (essentially $\emptyset$ ohms) whereas an incandescent light bulb has more ($\sim$150Ω for 100 watt bulb). A broken wire or an open switch has infinite resistance.

Direct Current (DC): The current flows in only one direction. Batteries provide direct current.

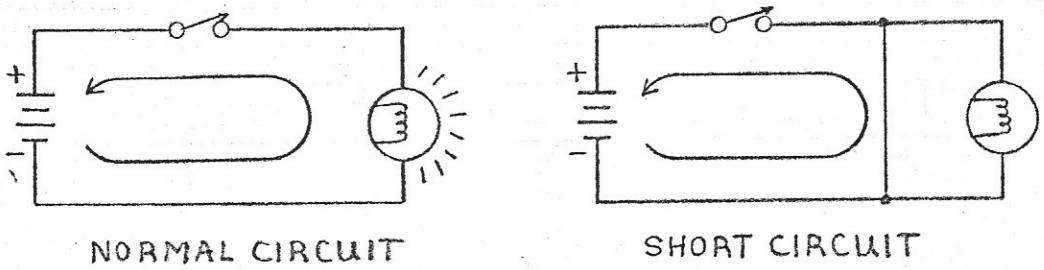
Alternating Current (AC): The current flows first in one direction and then reverses and flows in the opposite direction. Most houses and buildings have AC, which changes direction 60 times each second.

NOTE: Many devices, including most that have motors, are made to operate on AC or DC but NOT BOTH.

Load: Any device that draws current from the power source (load is measured in ohms). A large load draws more current than a small load; thus a large load has less resistance than a small load (see Ohm's Law). Motors, light bulbs and buzzers are examples of loads.

Open Circuit: A circuit which has a broken path. It can be intentional (such as by opening a switch) or undesired (such as a broken wire or a burned out light bulb). NO CURRENT FLOWS IN AN OPEN CIRCUIT.

Short Circuit: Any circuit which contains a current path other than the path intended.



NORMAL CIRCUIT SHORT CIRCUIT

CURRENT DOES FLOW IN A SHORT CIRCUIT - USUALLY MORE THAN IN THE NORMAL CIRCUIT

Connection: A point at which two or more components are joined (wire to terminal; wire to wire, etc.)

Connector: A device for joining two or more circuit components together. Most often it is applied to devices such as plugs and jacks.

Plug: A "male" connector.

Jack: A "female" connector. Same as receptacle or outlet.

Terminal: A point on a circuit component (such as switches, batteries, plugs, jacks, etc.) which is provided for connecting the component to the circuit. (eg. wires are soldered to terminals).

Wire: Wire is supplied in all types: insulated, non-insulated; copper aluminum, steel, solid; stranded; various thicknesses. Most wire we will be concerned with will be: insulated, copper, stranded and of moderate thickness.

a) Insulation prevents the wire itself (the conductor) from inadvertently touching another wire or component and creating a short circuit.

b) The metal (usually copper) is the conductor-that which actually allows the current to flow.

c) Stranded wire is more flexible than solid and does not break as easily when repeatedly bent.

d) Wire Thickness. Thicker wire (the conductor, not including the insulation) will allow more current to flow without heating up and possibly melting the insulation. Wire thickness is specified by wire gage (AWG, American Wire Gage) number. #16, #18, #20 (or 16,18,20 gauge) are the thicknesses we will most often be concerned with. #16 is thicker than #20 (smaller number = thicker wire).

III. Voltage-Current Relationship

a) OHM'S LAW: $V = I \times R$ (sometimes written $E = I \times R$)

V (volts) = I (amps) x R (ohms)

This means that when the voltage from the power source is constant the greater the resistance the less current that the source must provide. Batteries will last longer when they do not need to provide much current. (eg. connecting a wire across the battery terminals will run down the battery very quickly because R is very small and therefore I must be very large).

b) $I = \frac{V}{R}$

When the voltage and the resistance are known the current can be calculated.

c) Power: Power (in watts) = V x I

$$P = \frac{V^2}{R}$$

$$P = I^2R$$

Power can be calculated when any two of the three values are known. Most often the power that a device consumes will be known and we will wish to determine the current that it requires. This is important, for example, when a different switch or plug is to be used so that we can be sure to use one which is designed to handle the current.

Example: A 1200 watt hairdryer which operates on 120 volts AC:

$$P = V \times I$$

$$I = \frac{P}{V} = \frac{1200}{120} = 10 \text{ amps}$$

d) Amp-Hours: Batteries are rated according to amp-hours. This means that a 1 amp-hour battery will deliver one amp continuously for 1 hour;

after 1 hour it will not be able to deliver a full 1 amp and the current that it can deliver will continue to decrease until the battery is completely discharged. A battery can deliver less current than its rating for longer periods of time or more current for shorter periods. Example: 1 amp-hour battery will deliver:

1 amp for 1 hour

2 amp for ½ hour

½ amp for 2 hours

1/10 amp for 10 hours

IV. Types of Switches Connects 2 wires to complete a circuit.

Switches can fall into two general categories - latching and momentary. A latching switch is one which upon being activated remains activated until the operator returns and deactivates it. Light switches are examples of latching switches.

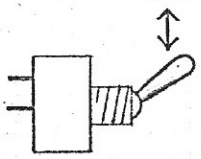
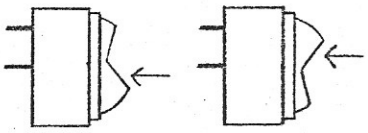
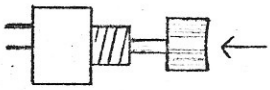
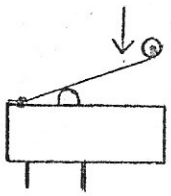
A momentary switch is one which remains activated only so long as the operator physically holds it and which is deactivated when the operator releases it. Doorbells, typewritter keys and push-button telephones are examples of momentary switches.

Switches can be of several types. Toggle, Rocker, Micro-switches, Push-button, Rotary and Mercury switches are the ones which are seen the most often. With the exception of the mercury switch and the rotary switch these switches can be either momentary or latching. The rotary switch is almost always a latching type. The mercury switch is a special case because its orientation in space determines whether or not it is being activated or deactivated (see Figure). It can be incorporated in a latching switch such as a "silent" wall switch but it is most often used in rehabilitation to respond

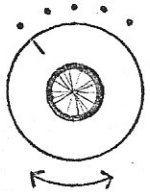
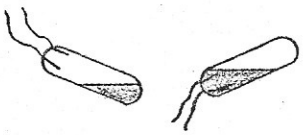
to positional change, such as in the head position feedback devices.

The unactivated position of a momentary switch is called the "normal" position. Switches can be bought which complete one circuit in the normal position and then break the first circuit and complete a second circuit in the activated position. In this case the first set of contacts would be labeled "normally closed" (NC) and the second set of contacts would be labelled "normally open" (NO). The type of switches we will usually use will be either N.O. or N.C. since we are only concerned with one circuit at a time. Furthermore we will almost always use a switch that is N.O. since we want to complete the circuit when the switch is activated.

Switches

Type	Characteristics	Uses
Toggle 	Usually latching type	Power ON/OFF Selecting between 2 devices
Rocker 	Usually latching type. Requires about same motor control as push button-same action.	Same as toggle switch-electrically interchangeable but requires different mounting hole.
Push Button 	Usually momentary type. Latching type sometimes called "push on-push off".	
Microswitch 	Momentary type. Requires very little force and very little movement to activate.	Electrically interchangeable with push button switch but mounting is different.

Switches

Type	Characteristics	Uses
Rotary 	Latching type. Twist knob to switch. Requires grip strength and twisting motion (knob could be modified similar to door knob levers).	Selecting between several devices or functions.
Mercury 	Position dependent-tilting switch activates and de-activates it. Breakable-protect from being knocked by hard objects.	Responding to position or change in position. Attach to body segments (eg. head) to trigger positive or negative reinforcement for correct positioning.

A rocker, toggle, push button or microswitch which has the following number of terminals is usually described as follows:

# TERMINALS	DESCRIPTION
2	SPST
3	SPDT
4	DPST
6	DPDT

Single Pole Single Throw

Double Pole Double Throw

Pole(s)= Number of separate circuits which can be switched at each switch position.

Throw= Number of switch positions

eg. SPDT = One circuit in position #1 and one different circuit in position #2.

SPST = One circuit; only one active switch position.

DPDT = Two circuits in position #1 and 2 different circuits in position #2.

V. Soldering

Equipment:

1. Soldering Iron - A soldering iron rated at about 25 watts is sufficient for most uses. An iron with a higher rating generates more heat and increases the risk of melting the insulation on the wire or switch.
2. Solder - Electronics solder should be used. Solder should be "Rosin-core". NEVER use "acid-core" solder!
3. Flux - Additional flux will not be needed if rosin-core solder is used. The flux cleans the metal and helps the solder to flow over the pieces to be soldered. Flux is used when the solder is solid core. Rosin is flux.
4. Wire strippers -

5. Wire cutters -

Preparation:

1. Ensure all surfaces to be soldered are clean and free from tarnish, oils or other coatings. Surfaces can be rubbed lightly with fine sandpaper or steel wool until metal is bright.
2. VERIFY SOLDERING IRON IS OFF

   Check soldering iron tip to be sure it is clean and has a thin coating of solder on it.

   If the tip is not clean or does not have a thin coating perform the following:

   a) Rub tip lightly with fine sandpaper until metal is bright.

b) Plug in solering iron and allow it to heat up. Test often by touching solder to tip - when tip is hot enough to melt solder coat approximately 1/8" to 3/16" of the tip with solder. This is called "Tinning".

c) Unplug the soldering iron until you are ready to solder. Tinning the tip improves the transfer of heat from the iron to the workpiece. Once tinned the tip will remain tinned indefinitely provided that the iron is not allowed to overheat by being left on and unused for more than one or two minutes. The better (and more expensive) irons have self-regulating thermostats - these can be left on longer without affecting the tip.

To Solder (General):

1. Arrange all materials and equipment conveniently.
2. Position the piece to be soldered to so that it is secure and will not move when the iron or the mating piece is pressed against it.
3. If a wire is to be soldered to a terminal, or another wire, the stripped end of the wire can be wrapped around the terminal or the other wire. This will prevent the two pieces from moving relative to each other.
4. Press the tip of the soldering iron against BOTH pieces simultaneously. Wait for pieces to heat up (1-4 seconds) and touch solder to pieces (not the iron).
5. When the solder melts and sufficient solder has flowed over the junction remove the soldering iron from the workpiece.

NOTE: It is very important that the two pieces not move relative to each other while the solder is cooling. Should they move, the bond will be severly weakened- known as a "cold solder joint". A good bond will appear smooth and shiny. A cold solder joint will appear as a dull grey.

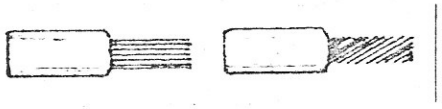
6. If a cold solder joint has resulted it can be remedied by reapplying the soldering iron to the joint until the solder again melts and then removing the iron and ensuring that the pieces do not move again relative to each other.

To Solder Wire:

When soldering a wire the following steps will make the task much easier and reduce the risk of damaging the component (switch, jack, etc.)

Preparations:

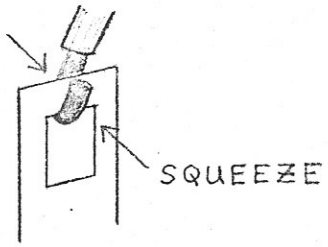
1. Use stranded wire.
2. Using the wire strippers strip approximately 3/8" of the insulation away from the wire. Be careful not to cut the wires themselves.
3. Twist the exposed wire end.



4. Place the tip of the soldering iron against the wire and touch the solder to the wire. The solder will melt and flow into and around the wire strands. Stop adding the solder when the strands are saturated but before the solder wells up and forms a drop on the wire. This is also called "Tinning".

Soldering to Terminals:

1. "Tin" the wire ends.
2. Bend the tinned end of the wire in the middle to form a "U". Needle-nose pliers work well for this.
3. Insert this end into the hole in the terminal. Use the needle-nose pliers to squeeze the wire end firmly around the terminal.



4. Place the tip of the iron against the terminal and the wire simultaneously. When the solder on the wire melts again add additional solder by touching the wire and terminal with the solder. When a small bead forms around the wire and the terminal stop adding solder and remove the iron.
5. The wire should now be firmly attached to the terminal.

How to Add a Switch in Parallel

Materials List

Jack (optional) (mini-microphone is suggested)

Switch

Wire (insulated)

Solder (rosin-care)

Soldering iron

Drill (if installing a jack)

Wire cutters

Wire strippers

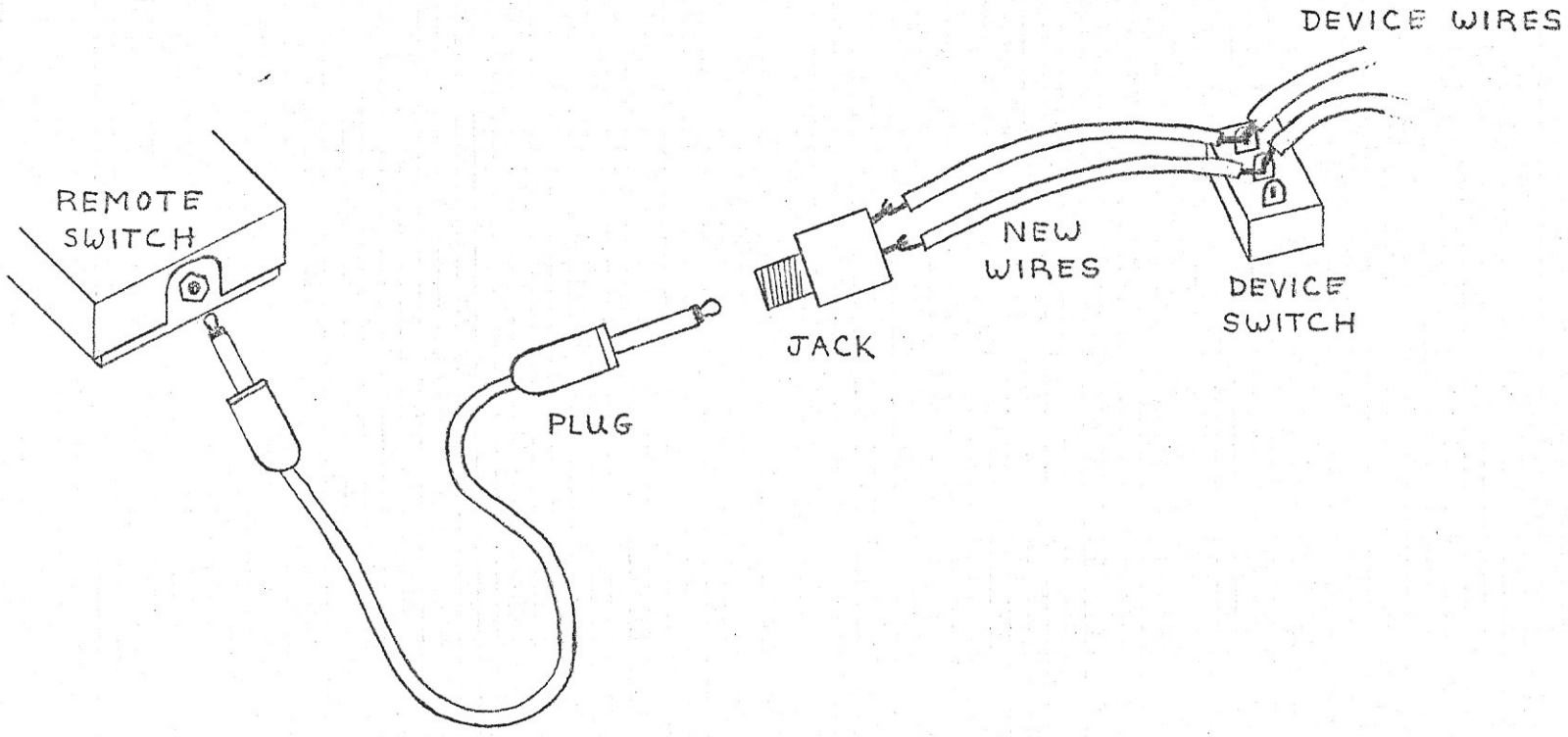
Needle-nose pliers

How to Add a Switch in Parallel

A. With a Jack

CAUTION: Do not attempt to modify a device that uses AC Power. Consult an engineer or technician if you wish to modify such a device.

1. Remove the batteries.
2. Open the device and locate the terminals on the back of the switch that you wish to modify.
3. If only two of the terminals have wires connected to them then you will be able to install a jack in parallel with the switch.
4. Acquire a jack that will mount on the device (usually called "panel mount" or "chassis mount"). A mini-microphone jack is a good choice because it is small and durable. Also, the Zygo switches all use mini-microphone jacks.
5. Determine a location on the outside surface of the device for the jack and then verify that there is sufficient room inside the device for the body of the jack.
6. Once the jack location has been determined you will need to drill a hole to mount it. The hole should be just slightly larger than the threaded shaft of the jack (¼" hole for mini-microphone jack).
7. Cut two wires to a length that is about one inch longer than necessary to reach from the switch to the jack. Prepare the wire ends for soldering (see: soldering wires).
8. Solder one wire to each terminal on the switch that has a wire already connected to it.



SWITCH IN PARALLEL
(WITH JACK)

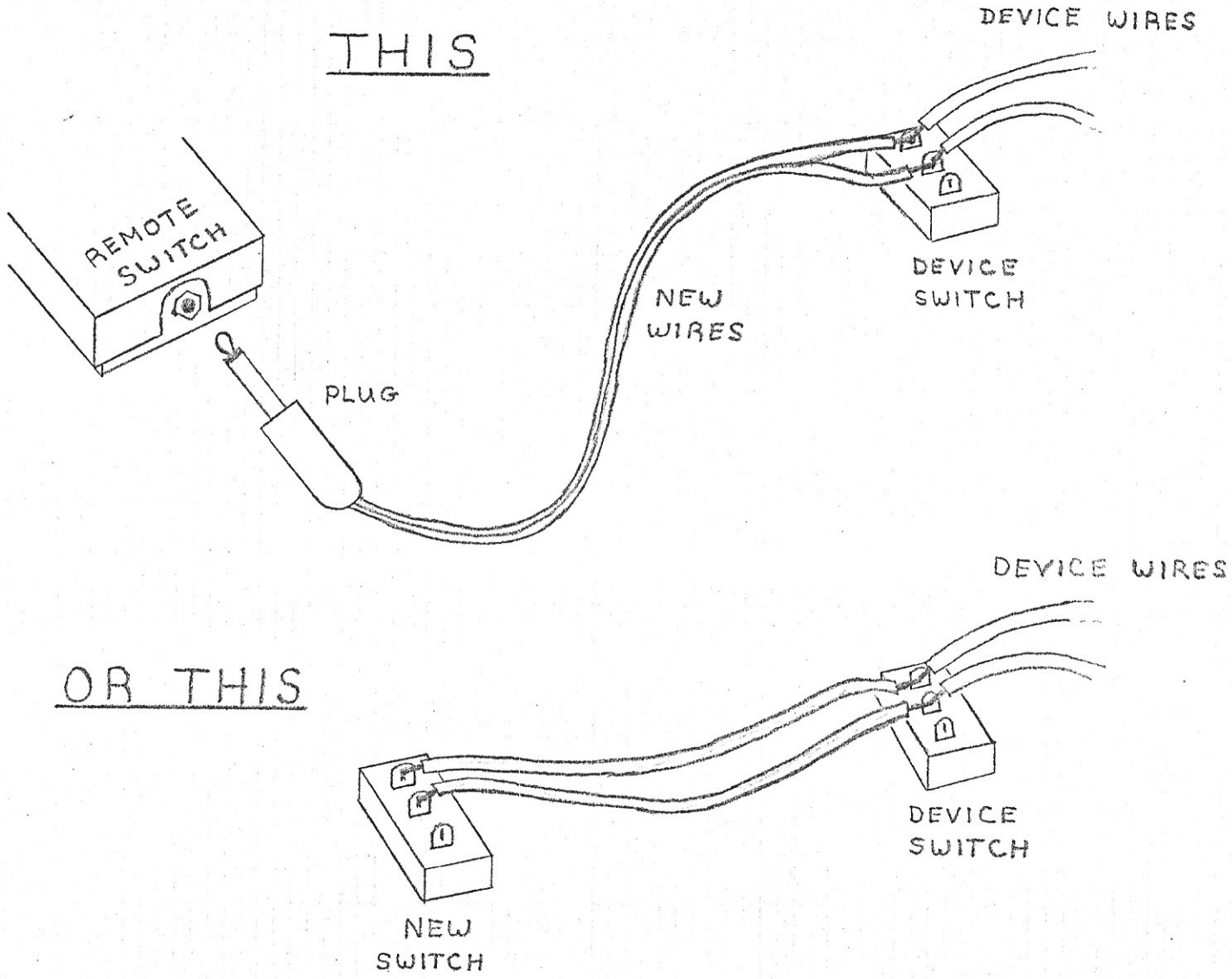
9. Solder the other end of each wire to a terminal on the jack.
10. Mount the jack in the previously drilled hole.
11. Test by inserting a plug with a switch connected to it into the jack. Activate the new switch and verify that it results in the same action as the existing switch.

B. Without a Jack

CAUTION: Do not attempt to modify a device that uses AC Power. Consult an engineer or technician if you wish to modify such a device.

1. Remove the batteries.
2. Open the device and locate the terminals on the back of the switch that you wish to modify.
3. Note the number of separate terminals that have wires connected to them. If only two terminals have wires connected to them then you can use a SPST; however, if more than two terminals have wires connected to them then you will need to use a switch with the same number of terminals in the same configuration. Rocker, toggle, pushbutton and microswitches are all available in similar configurations.
4. Determine the location for the new switch and then determine how long the wires will need to be to reach from the new switch to the existing switch. IF the new switch is to be located away from the device be sure that the wire will not interfere with other activities and that others will not trip over it.

5. Cut the wires to the needed length. You will need one wire for each terminal that has wires connected to it.
6. Prepare the ends of the wire for soldering (see: soldering wires).
7. Solder one wire to each terminal on the new switch that corresponds to the terminals on the existing switch that have wires connected to them.
8. Route the wires the way you will want them when you are finished and then solder the ends to the existing switch, being sure that each wire end is connected to the terminal that corresponds to the identical terminal that it is connected to on the new switch.
9. Check all connections.
10. Test by operating the device with the new switch. Verify that the original switch is still operating properly.

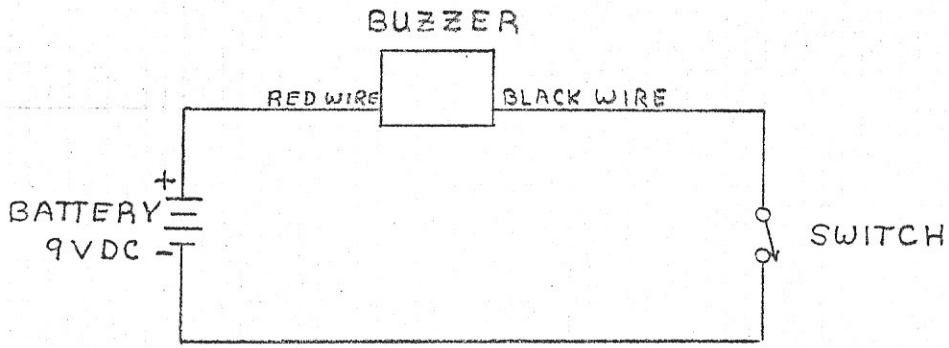


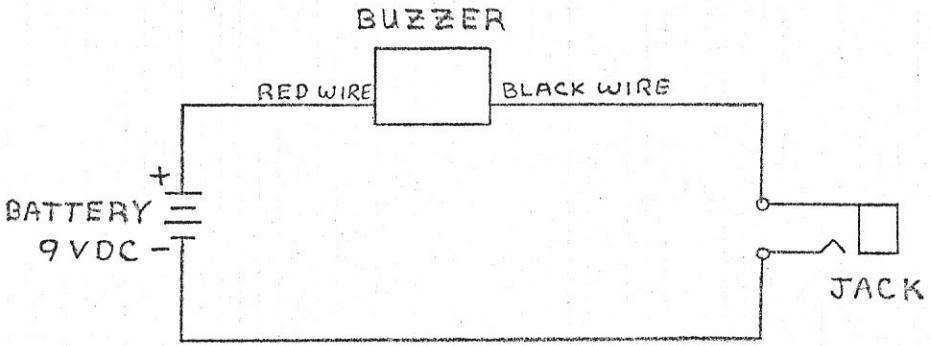
SWITCH IN PARALLEL
(WITHOUT JACK)

How to Make a Buzzer Box

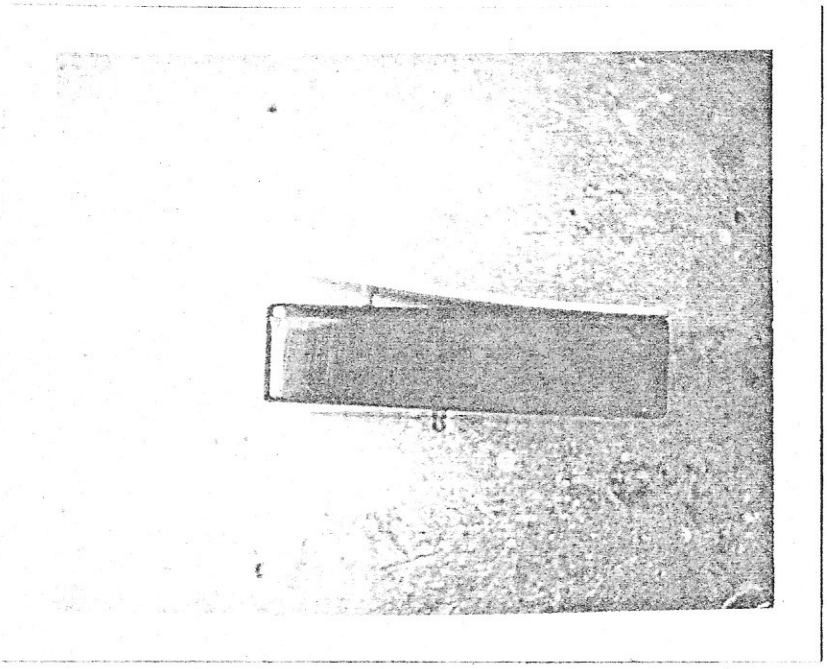
Materials List

Box w/Jack	Box w/o Jack	
✓	✓	Box (Hammond Mfg. P/N:1591 ABU; 4"x2"x.844"; Plastic)
	✓	Switch-pushbutton momentary (Alco P/N:MSP-103C)
✓	✓	Buzzer (6-9 VDC Mini-Buzzer)
✓		Jack (mini-microphone type is recommended)
✓	✓	Wire (insulated)
✓	✓	9V Battery
✓	✓	Battery Terminal Clips for 9V Battery
	✓	Plastic Paddle (2"x4"x1/16")
✓	✓	Drill
✓	✓	Soldering Iron
✓	✓	Solder (rosin-core)
✓	✓	Wire cutters
✓	✓	Wire strippers
✓	✓	Needle-nose pliers
✓	✓	(2) Flat head wood screws, #4, 1/2" long

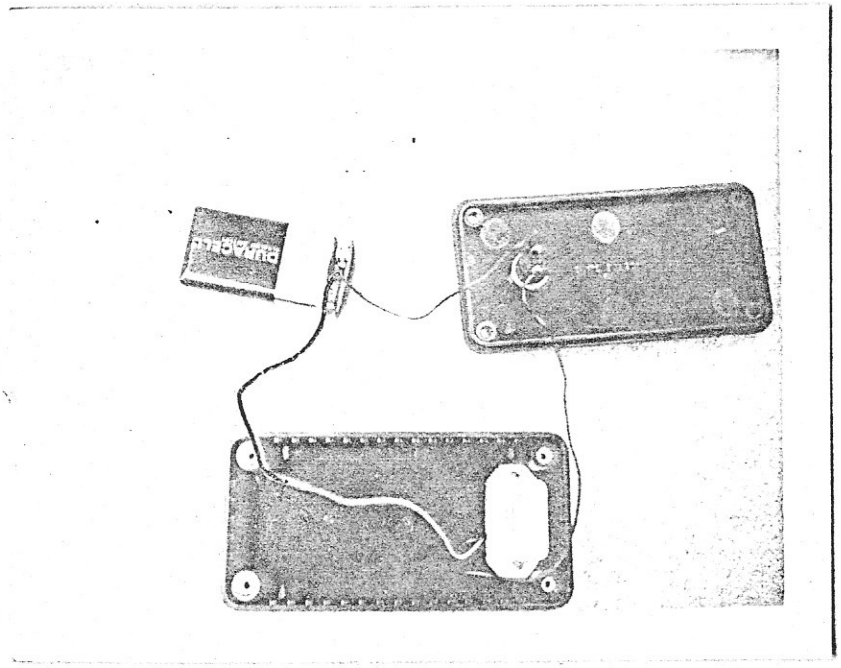




SCHEMATIC — BUZZER BOX

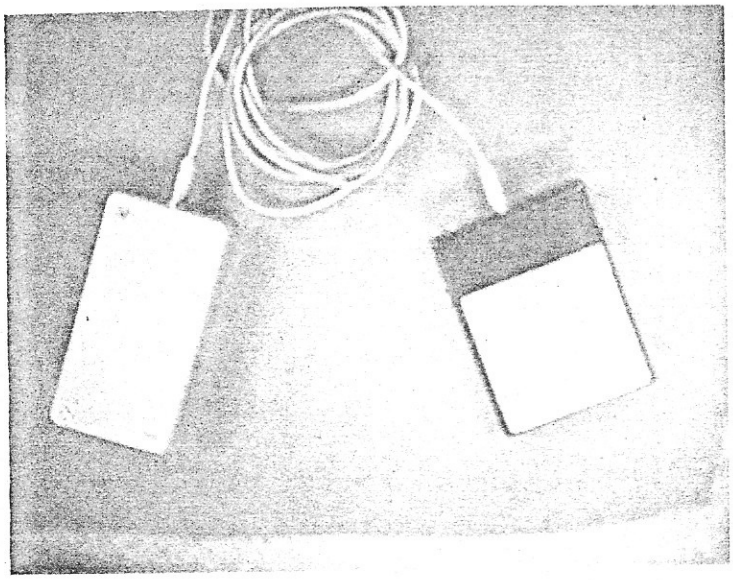


Assembled

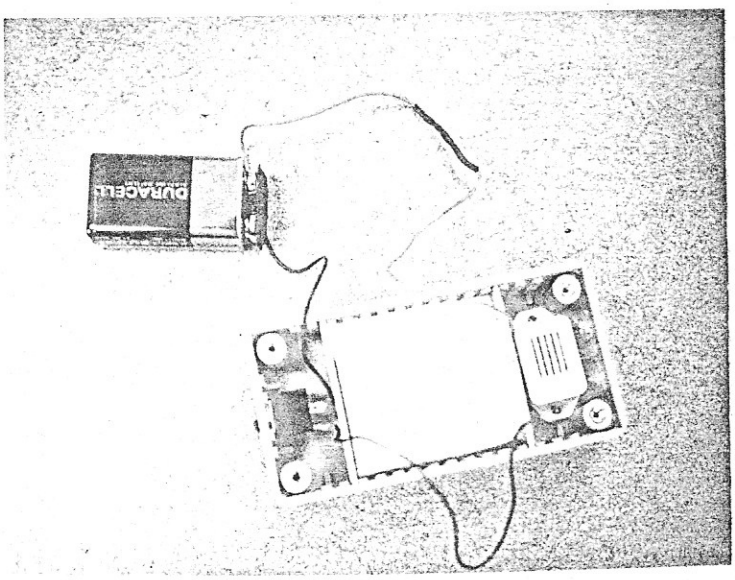


Disassembled

BUZZER BOX (WITH SWITCH)



Assembled



Disassembled

BUZZER BOX (WITH JACK)

How to Make a Buzzer Box

1. Determine which type of buzzer box you wish to make:

   a) one with a jack connection and an external switch;

   b) one which is self-contained with a paddle switch mounted on top.

2. Examine the figure which corresponds to the type of box which you wish to make. Note the location of each of the components.

3. FOR SWITCH INSTALLATIONS:

   Drill a ¼" hole in the cover of the box. The hole should be centered between the two sides and about 1" in from the end. Mount the switch.

4. FOR JACK INSTALLATIONS:

   Drill a ¼" hole in one end of the box. Center the hole top to bottom and side to side. Mount the jack.

5. Position the buzzer in the box as close as possible to the end opposite the jack and/or switch. Mark the box where the centers of the mounting holes on the buzzer line up. Remove the buzzer.

6. Drill a 1/8" hole in the bottom of the box where each of the marks were made.

7. Drill 4 or 5,1/8" holes in the end of the box to allow the sound of the buzzer to escape.

8. Mount the buzzer in the box by inserting the screws through the bottom of the box and into the mounting holes on the buzzer.

9. Prepare the ends of the wires from the battery clips and the buzzer for soldering (see: Soldering Wires).

10. Solder the red wire from the battery clips to either terminal on the switch or jack, whichever is being used.

11. Solder the red wire from the buzzer to the remaining terminal on the switch or jack.

12. Solder the remaining wire from the battery clip to the remaining wire from the buzzer. Wrap the connection with electrical tape.

13. Install a 9V battery and close the box. Do not install the screws in the cover yet.

14. Press the switch (if a switch has been installed), or plug a remote switch into the jack, and the buzzer should sound. If it does not, check the connections and try a new battery.

15. If a jack has been installed replace the screws in the cover. THE BOX IS COMPLETE.

16. If a switch has been installed install the two screws in the cover closest to the switch.

17. Drill 2 holes in the 2"x4"x 1/16" plastic so that the two remaining screws will pass through these holes and line up with the holes in the box cover. Attach the plastic paddle to the box. THE BOX IS NOW COMPLETE.

SWITCH ADAPTION FOR BATTERY OPERATED TOYS

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MATERIALS

22 Gauge Copper/Silver Speaker Wire ($.08 p/ft)

1/8" Phone Plugs (2 @ $1.29)

Double Backed Copper Plating ($.99)

Electronic Solder ($.99)

Switch (Realistic Foot Switch $3.99;
Zygo Pedal Switch $11.95;
H.C. Electronics Leaf Switch $15.00)

Battery operated toys

Transistor radio or tape recorder

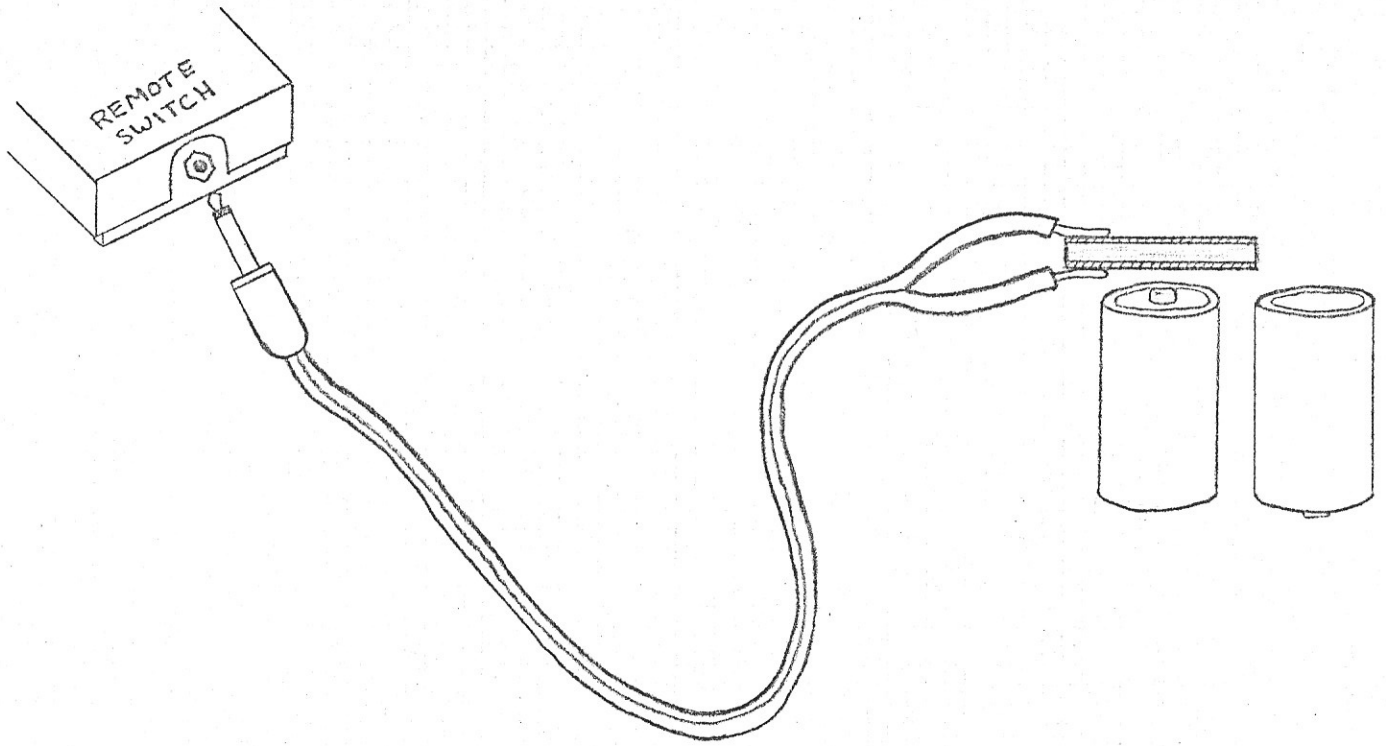
TOOLS

Soldering Iron ($3.99)

Wire Strippers ($2.99)

Wire Cutters ($4.95)

Materials and tools available at local hardware stores, Handyman or Radio Shack.



TOY ADAPTER

(1) Cut wire to desired length (4-5 feet is recommended).

(2) Using wire strippers remove ½" of the plastic tubing being careful not to break the exposed, uncovered wires.

(3) Cut a ½" or 3/4" square of double backed copper.

(4) Place silver wire on one side of the 3/4" copper plate and adhere with solder. (Fig. A)

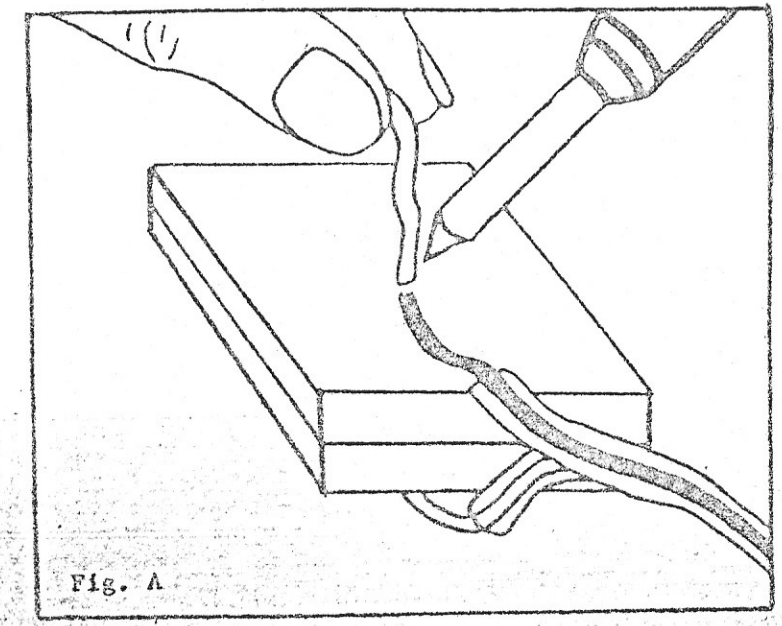


Fig. A

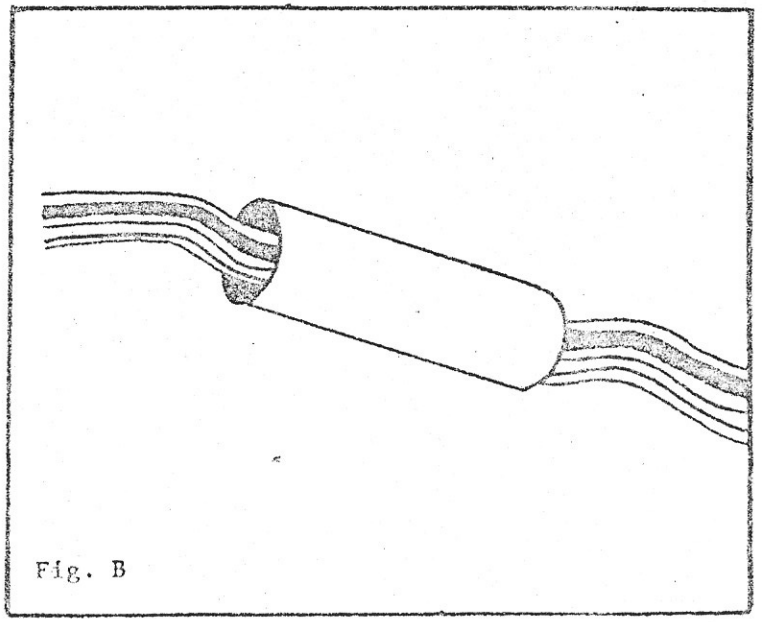


Fig. B

(5) Solder copper wires to the reverse side of the copper plate being certain that the two stripped wires do not make contact.

(6) Allow solder to cool.

(7) Unscrew phone plug and feed the plastic cap through wire for later concealment of wires soldered to plug. (Fig. B)

(8) Strip wires approximately ½" and thread each side (copper; silver) through the small hole on each plug prong. The stripped silver wires must not touch the stripped copper wires. (Fig. C)

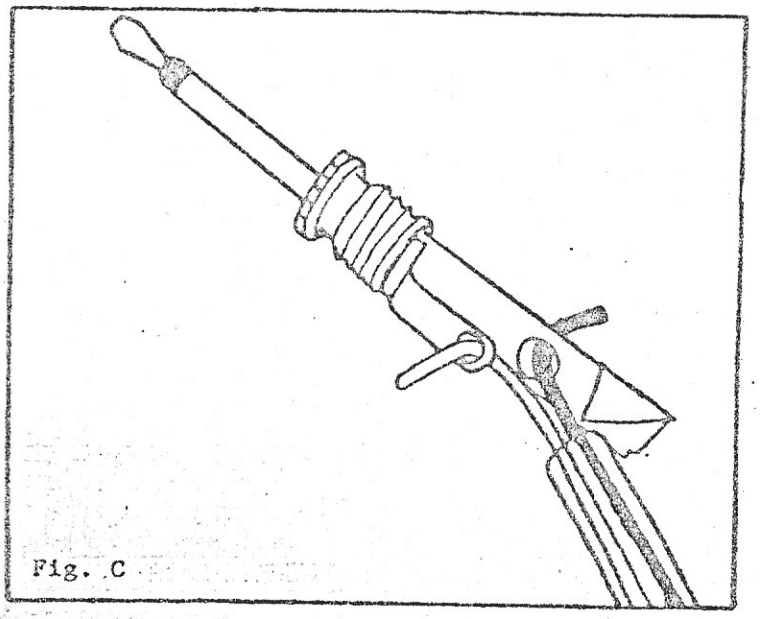


Fig. C

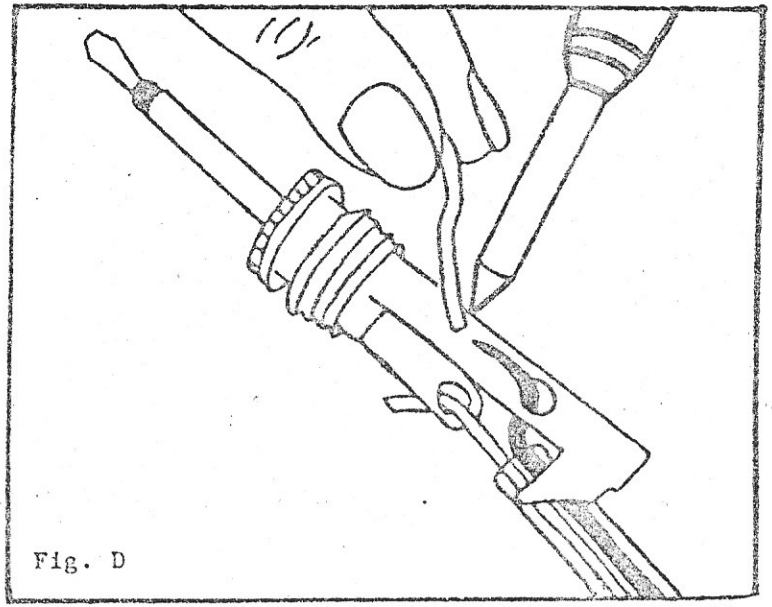


Fig. D

(9) Using a small amount solder the wires to the plug prong. (Fig. D)

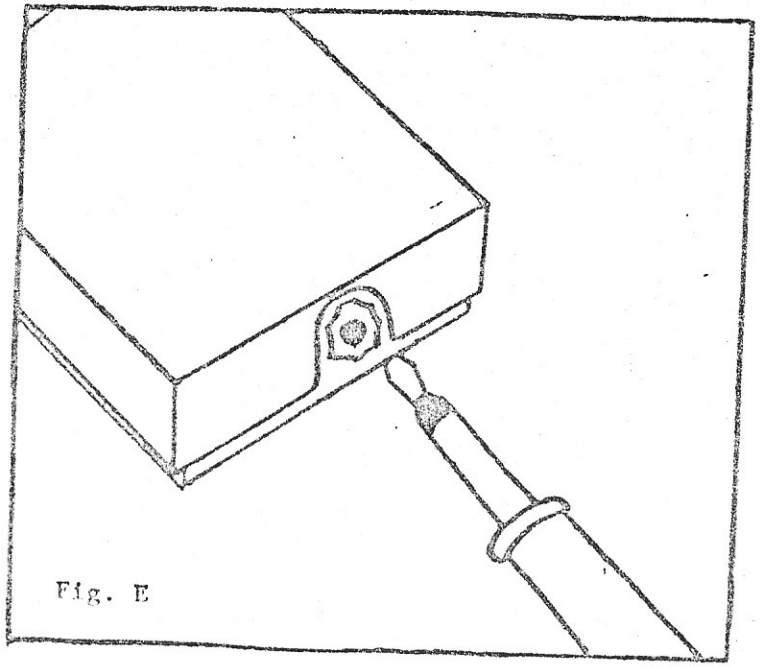


Fig. E

(10) When cool, screw the plastic cap onto the soldered phone plug.

(11) Plug the phone plug into the switch you have selected (i.e., Zygo Pedal Switch; Realistic Foot Switch). (Fig. E)

(12) Place the copper square on the positive (+) battery of the selected toy and carefully close and latch chamber. (Fig. F)

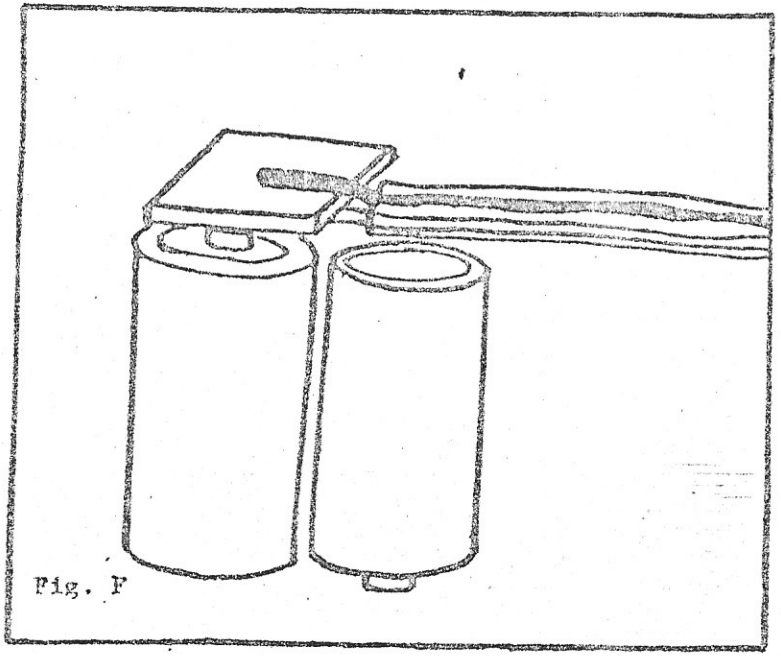


Fig. F

Fuse
Circuit Breaker

WHERE TO OBTAIN SWITCHES

(1) Zygo Industries, Inc.
POB 1008
Portland, Oregon 97207

(2) Everest & Jennings, Inc.
1803 Pontius Avenue
Los Angeles, CA. 90025

(3) H.C. Electronics, Inc.
250 Camino Alto
Mill Valley, CA. 94941